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Atención sincronizada de tele rehabilitación en zonas rurales con apoyo de ayudas tecnológicas tele operadas: aplicación a un caso Colombiano

Synchronized telerehabilitation care in rural zones supported by teleoperated technological aids: application to a Colombian case

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Resumen

Objetivo: Este trabajo de investigación se centra en proponer y evaluar un modelo para la prestación de servicios de rehabilitación física apoyados en ayudas tecnológicas tele operadas, utilizando Internet como canal de comunicación para el cuidado de la población rural, y tomando como región de estudio, una subregión del occidente de Colombia alrededor el municipio de Santiago de Cali-Colombia. **Metodología:** A partir de la dinámica generada por la interacción entre el sistema de servicios y los usuarios, caracterizada por la ocurrencia de eventos, se construyó un modelo formal, utilizando una Red Petri Coloreada. Para ello, se propuso una metodología de modelado basada en un enfoque top-Down. **Resultados:** Se desarrolló y evaluó un modelo del sistema de atención utilizando redes de Petri, a partir de un caso de estudio consistente en el modelo de atención actual que ofrece un proveedor de servicios de salud típico de Cali denominado "Red de salud La Ladera ESE". Las mejoras ponderadas a través del sistema propuesto fueron: mayor objetividad de trazabilidad, rapidez de comunicación, mejor calidad de rehabilitación, así como la capacidad del nuevo sistema para contribuir a una mayor precisión en el diagnóstico inicial y posterior evaluación periódica de recuperación. **Conclusiones:** El protocolo propuesto basado en el modelo, permitió atender de manera concurrente y precisa el diagnóstico de hasta tres pacientes, mediante la implementación de ayudas tecnológicas para mejorar el soporte diagnóstico y permitir una posterior evaluación periódica de la recuperación del paciente.

Palabras clave: Red de Petri coloreada, Modelado formal, Telemedicina, Tecnología tele operada, Áreas rurales.

Abstract

Objective: This research work focuses on proposing and evaluating a model for the provision of physical rehabilitation services supported by teleoperated technological aids, using the Internet as a communication channel for the care of the rural population, and by taking as the study region, a western subregion of Colombia around the municipality of Santiago de Cali- Colombia. **Methodology:** From the dynamics generated by the interaction between the service system and the users, characterized by the occurrence of events, a formal model was built, using a Colored Petri Net. To do this, a modelling methodology based on a top-down approach was proposed. **Results:** A model of the care system was developed and evaluated using Petri nets, based on a case study consisting of the current care model offered by a typical health service provider in Cali called "La Ladera ESE Health Network". The weighted improvements through the proposed system were: greater objectivity of traceability, speed of communication, better quality of rehabilitation, as well as the ability of the new system to contribute to greater precision in the initial diagnosis and subsequent periodic evaluation of recovery. **Conclusions:** The proposed protocol based on the model made it possible to attend concurrently and accurately diagnose up to three patients, through the implementation of technological aids to improve diagnostic support and allow a subsequent periodic evaluation of the patient´s recovery.

Keywords: Colored Petri Net, Formal modelling, Telemedicine, Teleoperated technology, Rural areas.

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Introduction

One of the most felt difficulties by part of the rural population in emerging economies, such as Colombia, is stable and effective access to health services [1, 2]. This difficulty is further complicated in the times of lockdown generated by events such as the COVID-19 pandemic. In response, governments have reinforced policies that promote the implementation of telemedicine systems in health service models. This implies the integration of technologies and media in a system that allows users to access health services remotely, these are the Information and Communication Technologies (ICT) [3]. exposes that using ICT can allow physicians and patients to communicate 24/7, using smartphones or webcam computers. The Own elaboration mention that more than 50 U.S. health systems such as Jefferson Health, Mount Sinai, Kaiser Permanente, Cleveland Clinic, and Providence have already these programs and take advantage of telehealth technology to allow doctors to see patients who are at home.

In the field of physical rehabilitation, the implementation of this type of health services allows, with the help of medical protocols and the assistance of professionals in physical rehabilitation, to achieve to a greater extent the same effectiveness of face-to-face treatment with the patient, completing it with the same possibilities of recovering his/her mobility and strength affected by temporary injuries, and reintegrating him/her as an independent and autonomous individual into daily life. In Colombia, this type of health care service has been regulated since 2010, incentivized by demographic distribution. According to [1], approximately 75.7% of the population is concentrated in urban areas, where specialized health services, such as physical rehabilitation, are available. This reveals a vulnerable population with difficult access to specialized medical care. Similarly, the distribution of health service providers in the country is not proportional to the total need for regional medical services [3]. This has affected the quality of life of the people, particularly the people who have suffered some type of joint injury and are experiencing a situation of temporary disability according with the OMS and [4].

Several countries, such as Colombia through the Ministry of Health and Social Protection, have defined legal regulations oriented to telemedicine practice. In fact, recent studies present valid efforts to establish and validate alternative modes of health care, not only focusing on treatment and prevention strategies for an outbreak, but also seeing other benefits of telemedicine [5, 6, 7]. For example, in [8, 9, 10, 11, 12, 13] several approaches to monitoring and diagnosis are presented. In addition, [14, 15] offers solutions focused on education about health care. In [16, 17, 18, 19, 20, 21] generates Tele-rehabilitation applications, and [22, 23, 24, 25, 26] presents tele-operation characteristics. From the structural point of view, [27, 28, 29, 30] presents several health application using a service - oriented architecture (SOA), allowing to identify fundamental aspects of development, novelty, and construction of new knowledge. However, few investigations integrate a SOA application focused on monitoring, diagnosis, tele-rehabilitation with tele-operation characteristics. In this context, this research work considers this integration to propose a care model of tele-operated physical rehabilitation that allows permanent monitoring of the patient by the specialist. This solution for the vulnerable and geographically dispersed populations identified in the studied region offers an improved state of the tele-assisted rehabilitation service system, through which it is expected that not only the effectiveness of the treatments will be improved, but also that the number of unfinished physical rehabilitation therapies will decrease.

The aim of this study is to propose and evaluate a model for the provision of physical rehabilitation services supported by teleoperated technological aids, using the Internet as a communication channel, and apply it to the case of care of the rural population of the municipality of Santiago de Cali- Colombia. For this, it was required to develop a simulation model that represents the current and improved state of the studied

system, and that contributes to the evaluation of different improving options, as well as to demonstrate the impacts of the integrated technologies in the different activities defined in the improved protocols of attention.

The simulation model is based on Colored Petri nets (CPN), the improved state implies the inclusion of teleoperated technological aids, using the Internet as a communication channel, for the application of physical rehabilitation protocols.

This paper consists of six sections organized as follows: section two presents the literature review about advances in telemedicine applied to rehabilitation processes, section three shows the methodology developed to achieve the research objective, then section four describes the case study, section five shows the research results and finally, the conclusions are presented in section six.

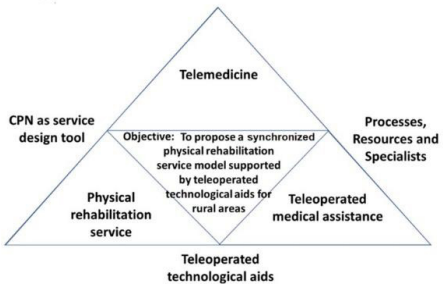
Methodology

Based on the research question posed and the advantage of having the CPN tool as a design tool to simulate the proposed system in accordance with the CPN Group guidelines [31].

This applied research was based on observation to characterize the current state of the care service, and the visualization of the integration of teleoperated technologies for increasing system capacities to translate into the future state.

The global methodology formulated is represented in Figure 1, which shows, on one hand, the integration of three concepts used: telemedicine, physical rehabilitation service and teleoperated medical assistance, and on the other hand, three synchronized enablers used for the proposed model: CPN as a service design tool, teleoperated technological aids and, processes, resources and specialists of the system.

Figure 1. Research methodological framework

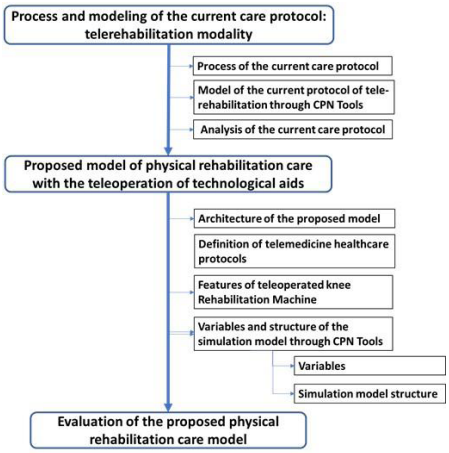


Source: Own elaboration

The results of this research were analyzed using mainly qualitative variables since the objective is focused on raising the capacities of the health network in relation to its current state. For this, the modified architecture of the current attention service is proposed. Likewise, options or scenarios of the proposed architecture are evaluated, based on the conditions they offer for better information management and rehabilitation treatments.

The modelling procedure for the redesign of the architecture of the care system (see Figure 2), allowed to work with the relevant information on the current architecture, to migrate to the architecture that incorporates the teleoperated technological aids, based on a methodical characterization of actors, relationships, processes, resources, among other aspects, to answer the research question in a practical way.

Figure 2 Service system modeling and redesign procedure

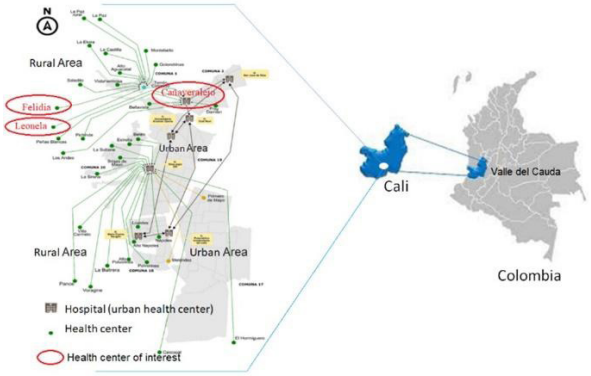


Source: Own elaboration

Case Study

For the application of the methodology developed in this research, a rehabilitation service offered by a health provider institution called "Red de salud La Ladera E.S.E." was selected. This institution is in Cali, capital of Valle del Cauca department in Colombia, see Figure 3.

Figure 3 Geographical location of the study



Source: [32]

In the context of Cali, the Ladera Network is the most extensive in its area of influence, provisioning of services to the homeless or at-risk population as: victims of the internal armed conflict, indigenous and afro-descendant population. They are people who generally live-in vulnerable areas, with difficult access to an urban health center due to economic, social and road mobility-related factors. This institution implemented since 2014 a telehealth service through the Internet, which provides the conditions for remote rehabilitation sessions led by specialists, physiotherapists, who through ICTs, and with the support of trained auxiliary nurses located in rural health centers, perform tele-directed therapies to patients, following the rehabilitation protocols established for each type of injury. The case study integrates three health centers, two located in the rural area, La Leonera and Felidia, where the patients are, and one located in the urban area, Cañaveralejo, where the physical therapists are.

Results

According to the methodology, information was collected on the current system to learn about the functioning of the system, in terms of its process flows, its components, interactions and resources. For this, field visits were made, the processes to be modelled were recognized, and interviews were conducted with the technical and professional staff involved. The results are presented.

Process and modeling of the current care protocol: telerehabilitation modality without technological aids

- **Process of the current care protocol**

Currently, La Ladera E.S.E. Network offers a care protocol that considers three stages, diagnosis, intervention, and evaluation. When the diagnosis is completed, then, in the second stage, if the modality of patient care is telemedicine, the patient must go to the nearest health center of his place of residence. At the end of the session, according to the result of the therapy, the specialist records the information in the patient's evolution form.

The information about the type of injury or pathology of the patient is a medical record used by La Ladera E.S.E. Network service system to contact the patient, so that he can go to the nearest rural health center and start the rehabilitation treatment.

To characterize the system as a process, SIPOC is the appropriate six sigma methodology tool [33], as it provides teams with a high-level understanding of the main process components and boundaries. In this investigation, the SIPOC diagram also helped to identify internal customers, as well as the real problems in the rehabilitation process.

Table 1 and Table 2 show the SIPOC for the general treatment process and the rehabilitation therapy session process.

Table 1 SIPOC of the global treatment

SUPPLIER	INPUT	PROCESS	OUPUT	CUSTOMER
Doctor or orthopedist or physiatrist, Patient	Medical order, customer data and information about the injury	Register the medical order and patient data	Patient medical order and data registered	Prepare communication equipment, Specialist (physiotherapist)
Register the medical order and patient data	Patient medical order and data registered	Prepare communication equipment, Specialist	Communication equipment prepared	Make the first physical diagnosis
Prepare communication equipment, Specialist	Communication equipment prepared	Make the first physical diagnosis	Physical diagnosis realized	Schedule the rehabilitation sessions
Make the first physical diagnosis	Physical diagnosis realized	Schedule the rehabilitation sessions	Scheduled rehabilitation sessions	Realization of the rehabilitation sessions
Schedule the rehabilitation sessions	Scheduled rehabilitation sessions	Realization of the rehabilitation or intervention sessions	Rehabilitation sessions realized, Report of the patient evolution	Doctor or orthopedist or physiatrist, Patient

Source: Own elaboration

Table 2 SIPOC of Treatment for the rehabilitation or Intervention sessions in therapy

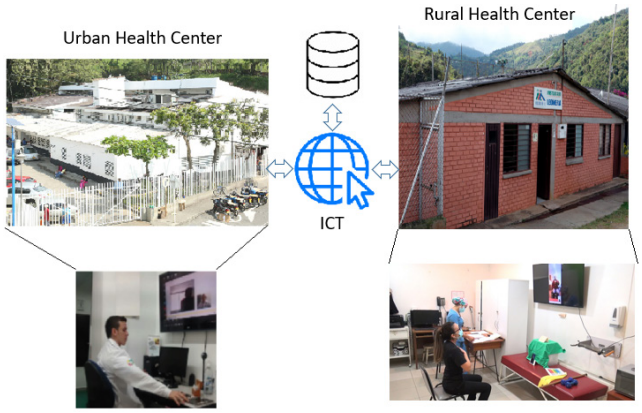
SUPPLIER	INPUT	PROCESS	OUTPUT	CUSTOMER
Patient	Patient, Patient information	Prepare patient information and communication equipment by the auxiliary nurse	Patient and information and communication equipment prepared	Realize the follow-up test by the physiotherapist
Prepare patient information and communication equipment by the auxiliary nurse	Patient and information and communication equipment prepared	Realize the follow-up test by the physiotherapist	Follow-up test result	Receive physiotherapist indications online and select physiotherapy resources and equipment
Realize the follow-up test by the physiotherapist	Follow-up test result	Receive indications online and select equipment	Therapeutic procedure established according to the indications of the physiotherapist	Accompany therapy according to the procedure followed by the auxiliary nurse
Receive physiotherapist indications online and select equipment	Therapeutic procedure established according to the indications of the physiotherapist	Accompany therapy according to the procedure followed by the auxiliary nurse	Realized therapy in the session	Elaborate report about patient evolution by the physiotherapist
Accompany therapy according to the procedure followed by the auxiliary nurse	Realized therapy in the session	Elaborate report about patient evolution by the physiotherapist	Registry of patient evolution	Patient

Source: Own elaboration

In this process, the provision of therapeutic elements for patient care is basic. Under the current conditions of the teleoperated service, rehabilitated patients located in rural areas are cared for by nursing assistants, who are trained in physical rehabilitation to carry out the direct instructions of physiotherapy specialists, located in urban areas, through visual and oral instructions using the Internet as communication channel.

Figure 4 illustrates the structural elements of the teleoperated rehabilitation service taken as an example.

Figure 4 Structural elements of the synchronized teleoperated service in the rural



Source: Own elaboration

- **Model of the current protocol of telerehabilitation through CPN tools**

Table IV shows the structural elements of the model. On one hand, the parameters are the conditions under which the model is running, on the other hand, the variables represent the information and dynamic characteristics of the model. In the model, a variable or the integration of different variables belong to a specific set, these sets are used to describe a parameter in the model. An example of parameters, its variables and the sets formed by these variables is shown in Table 3.

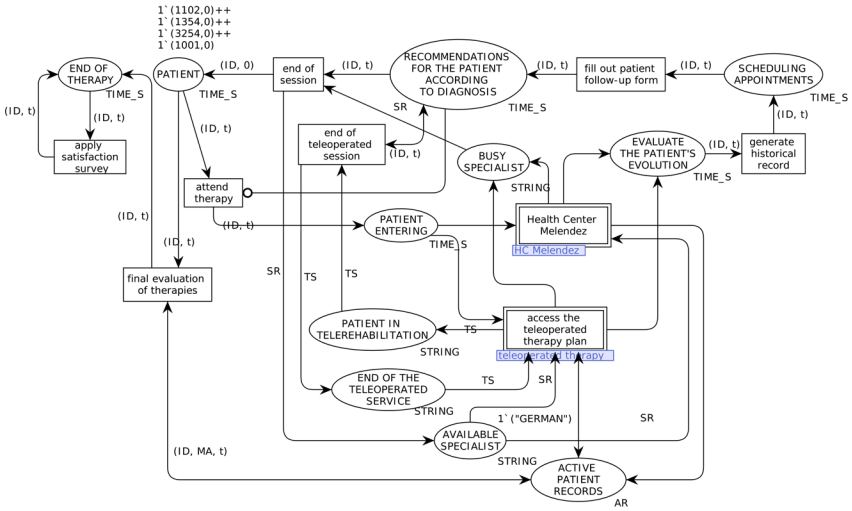
TABLE 3 STRUCTURAL ELEMENTS OF THE MODEL IN CPN TOOLS

PARAMETERS	VARIABLES	SETS
Patients with authorized medical order. Each medical order contains 10 therapy sessions. The patient is identified with the ID number. The patient has the option to be attended in person or Tele-assisted. The patient randomly decides the mode of care (Face-to-face or Tele-assisted). The patient arrives with pain or without pain, this condition is managed randomly, assuming 80% without pain, whether in person or tele-assisted.	(ID): ID card. (MA): Medical appointment. t: Number of times that patients has been treated. (PC): Pain condition Y / N. (SR): Specialist resource (Physiotherapist). (TS): Therapy status.	(AR): It is the appointment record. TIME_S: It is the record of the ID and the number of times that patients has been treated. EVOLUTION: It is the record of the patient's condition at the beginning of each appointment.

Source: Own elaboration

Figure 5 shows the <<General>> model of the care protocol for rehabilitation both face-to-face (represented by the red transition << Health Center Melendez >> and teleoperated (represented by the transition << access the teleoperated therapy plan >>). This model has as initial mark the information of the patients (ID number, therapy time), i.e. that represented by the mark << 1` (1102,0) ++ >>. The current protocol allows patients to choose between taking the therapies directly at the Health Provider Institute (HPI) or using the teleoperated rehabilitation service.

Figure 5 Main network of patient care modeling by La Ladera E.S.E.



Source: Own elaboration

- **Analysis of the current care protocol**

This model presents a deterministic condition of its processes, that is, if the resources are available, the simulation will not have any setbacks to the one normally established. It was verified by simulation that each part of the model network complied with the properties of reachability, liveliness, repeatability, and boundedness. The functional behavior of the model was in accordance with the requirements of the real system. The model made it possible to identify that the Teleoperated service under current conditions consumes all the resources “specialist” and “nurse” during the entire time of the session for the care of a single patient.

In addition, the current telerehabilitation service presents a limitation of the visibility that the specialist has on the performance of the exercises performed by the patient, because the nurse takes a considerable time (10-15 min) to fully understand the indications from the specialist, this causes the specialist to have to repeat the indications frequently, and that during the execution of the therapy, the patient has to correct the posture. These actions are reflected in delays in therapy, poor fluency and longer use of the “specialist” resource, generating waste.

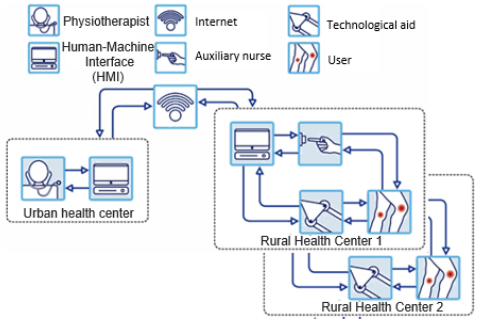
Proposed model of physical rehabilitation care with the teleoperation of technological aids

For the proposed model, this section presents the structural model, the architecture, and the simulation model, considering the incorporation of teleoperated technological aids to the telerehabilitation protocol. The section ends with the formulation of the scenarios to evaluate the simulations, and with the analysis of the results.

- ***Architecture of the proposed model***

Figure 6 presents the architecture proposed. This model is based on the simultaneous interaction of each of several patients treated in health centers distributed in rural areas of the city of Cali, with the physiotherapist, located in an urban health center. This interaction takes place in a synchronized way, using teleoperated technological aids and the assistance of the nurse.

Figure 6 Architecture proposed considering teleoperated technological aids



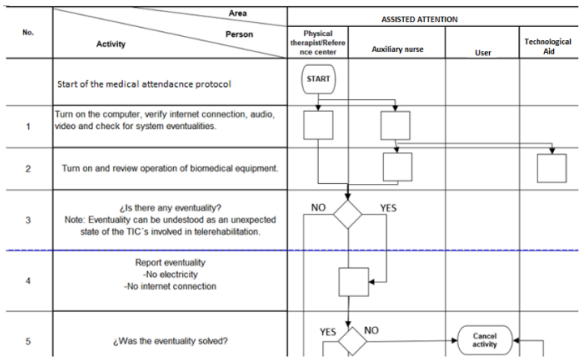
Source: Own elaboration

- ***Definition of telemedicine healthcare protocols***

Once the information on the current care protocol was collected, the activities that had to be added to include tele-operated technological aids were identified for the rural medical centers selected, La Leonera and Felidia. Consequently, using the proposed model, the care of two patients is performed simultaneously remotely. For this, the current protocol was modified by adding new activities in the case that eventualities could occur during the use of the technological aids, with the purpose of continuing the defined rehabilitation protocol, even if the technological aids are not in operation. In this sense, the eventualities of communication failure due to problems connecting to the communication channel (the internet), and / or the electricity supply were considered, in which instances in the current system, the rehabilitation session would be canceled.

In Figure 7 the changes made at the beginning of the protocol are shown, where prior to the therapy session, a verification of all the communication systems and the technological aids was added.

Figure 7 Changes at the start of the care protocol

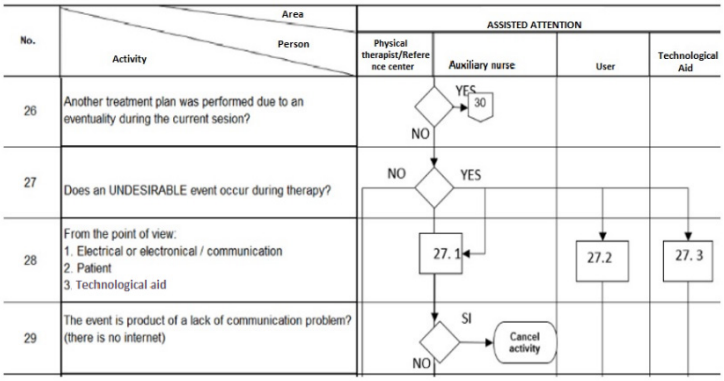


Source: Own elaboration

If the patient agrees to use the technological aid, the proposed protocol includes its use to perform the initial diagnosis, see Figure 8. This is advantageous for diagnosis because the measurements have quantitative support, which will help the specialist gain an improved perspective of the problem of the patient, therefore enabling them to provide a more accurate diagnosis supported by the results of the test performed by the technological aid.

The protocol contemplates the occurrence of three types of eventualities (energy/communication, patient and technological aid) that could occur under normal circumstances and states whether the therapy should continue, see in Figure 8, activity No. 28.

Figure 8 Use of the technological aid for diagnostic support

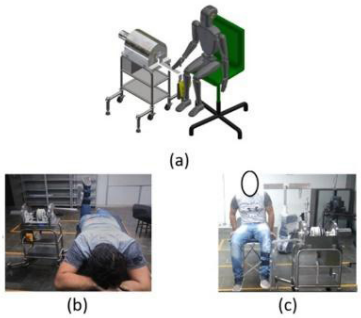


Source: Own elaboration

- ***Features of teleoperated knee rehabilitation technological aid***

The specific technological aid to be incorporated into the system, has among its characteristics, to facilitate the execution of active and passive knee rehabilitation protocols [34]. This technological aid was developed by the research group BIONOVO at Universidad del Valle, Cali-Colombia. It has an automatic mechanism for generating the movement required in a passive therapy rehabilitation protocol. (see Figure 9). The details of the developed equipment can be seen in [34,35].

Figure 9 Technological aid for telerehabilitation of the knee, (a) CAD design, (b) application of passive rehabilitation protocol and (c) application of active rehabilitation protocol



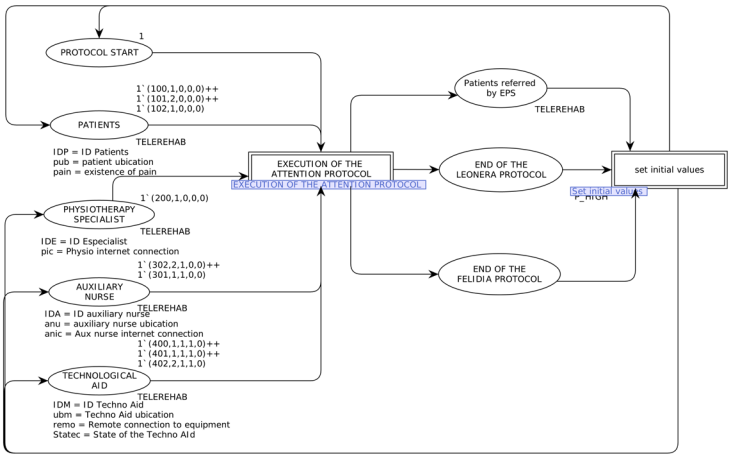
Source: [34]

- ***Structure of the simulation model through CPN tools***

Simulation model structure: Figure 10 shows the general model in CPN of the proposed care protocol. The main network has five entry points, corresponding to the resources "Patient", "Physiotherapist specialist", "auxiliary nurse", "technological aids" and "start protocol". Which are directed to the transition "execution care protocol", giving as output the "end of the Leonera protocol", "end of Felidia protocol" "patients referred to city branch". When the signal reaches these three places, the transition "set initial values" is activated allowing you to start the protocol again.

Figure 10 shows details of the initial marking that denotes the beginning of the protocol. all places (except for "start protocol") are of TELEREHAB type, that is, they are a list of integer values.

Figure 10 Diagram CPN general model.

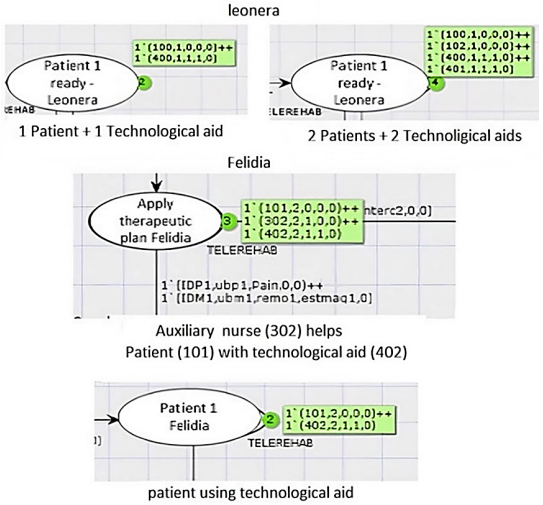


Source: Own elaboration

As an example, the markings for one of the patients [1` (100,1,0,0,0)] denotes that the patient's ID is 100, it is located at Leonera (1) and does not experience pain at the beginning of the protocol (0). There are two additional zeros, which correspond to available spaces in case you want to assign other parameters.

Multiple attentions: The proposed protocol allows for multiple attentions, see Figure 11 It can be observed, for example, that for Leonera, there is the possibility of treating a patient with the technological aid and up to two patients with two technological aids per session. On the other hand, in Felidia a patient can be served with one technological aid.

Figure 11 Multiple attentions



Source: Own elaboration

Evaluation of the proposed physical rehabilitation care model

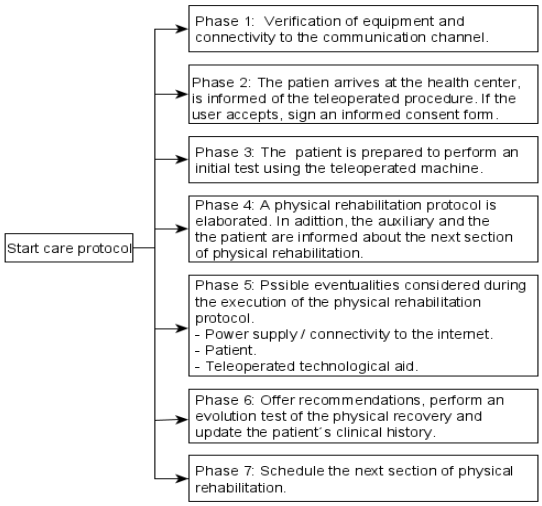
- ***Model and results validation***

To verify the model, the following aspects were considered:

- All patients, in both the current and proposed protocols, have access to teleoperated treatment (the first protocol does not include technological aids, the second does), so that no patient needs to travel to the urban health center to be treated.
- The proposed protocol allows one to three patients per session.
- The proposed protocol allows part of the diagnosis to be carried out with teleoperated technological aid. The variables that are measured are: joint position angle in passive mode and position, speed and force in active mode. Thus, offering support to the therapist's decision in a protocol rehabilitation.

  For the validation of the proposed model, it was verified by simulation that the network complied with the properties of reachability, vivacity, repetitiveness, and delimitation. The functional behavior of the model was in accordance with what was established in the proposed care protocol that integrates the use of technical aids for tele-directed rehabilitation. The validation process of the model was divided into seven phases, each of which is related to one or several activities of the proposed care protocol, see Figure 12.

Figure 12 Phases considered during validation



Source: Own elaboration

- ***Comparisons between the current and the proposed model***

Comparisons were made between the current and the proposed model, evidencing that with greater technological capacity and communication, greater health coverage can be achieved.

In addition, it was found that the system becomes more complex as a greater number of elements are integrated into the therapy. However, the integration of more elements into the process could provide a better service to a greater number of patients.

The proposed model, unlike the current model, does not exhibit a completely linear behavior, since it has some concurrent activities where the physiotherapist, nurse, patient, and the technological aid interact.

The use of a technological aid provides an element that the current system lacks support for the diagnosis. Validation of the model revealed that the average patient care time in the current model and the proposed model are similar. However, the addition of the technological aid provides additional information about the conditions of the patient; this information is supported by calibrated sensors that give greater reliability to the diagnosis of the therapist. This information could reduce the number of therapeutic sessions, since the therapies would be based on quantitative values and a historical record would be maintained, which could be accessed by a greater number of specialists if necessary. This could reduce the costs related to patient care. Once the protocol is implemented, indicators that quantify the improvement proposed by this project could be established.

Conclusion

The rural population of developing countries has serious difficulties in accessing specialized health services, including physical rehabilitation treatments. This problem was exacerbated by the disaster caused by the COVID-19 pandemic, further limiting the access of vulnerable populations to health in these contexts. This research work proposes a model for the provision of physical rehabilitation services supported by teleoperated technological aids, for the treatment of injuries in the knee joint, using the Internet as a communication channel for the care of the rural population, applying it to the case from the municipality of Santiago de Cali- Colombia. The model was evaluated using a Coloured Petri net.

Being a first approximation and not having a benchmark for comparison, the proposed model could only be qualitatively validated. The proposed protocol made it possible to attend concurrently and accurately diagnose up to three patients, through the implementation of technological aids to improve diagnostic support.

Although the improvement of service times is key in a service system of this nature, we have weighted four main advances in the service system under study. On one hand, greater objectivity of traceability, as an important capacity gained, facilitates the work of system administrators and servers, to the extent that the system records valid information on the development of therapies, contributing to greater reliability in the results and a better evaluation of the quality of the service. The other three advances potentially valued by the specialists and auxiliary nurses were the speed of communication, the quality of the rehabilitation and the capacity of the new system to contribute to a greater precision of the initial diagnosis and subsequent periodic evaluation of the recovery. This can be summed up in greater capacities in the telerehabilitation care system for vulnerable rural populations supported by teleoperated technological aids.

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